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Energy Crops: A New Challenge for Tropical Regions*

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ABSTRACT

Solar energy captured by plants through photosynthesis is not only the prime source of all of the world's foodstuffs but also is important in the generation of fuels. The main role of agriculture has always been the production of foods and fibers for mankind. In recent years, however, as a consequence of the oil crisis and the depletion of the world resources of fossil fuels, plant cultivation aimed at fuel production has been considered as a feasible alternative energy source, especially in tropical countries where solar energy is abundant.

This paper analyses the problem of fuel production from plants, on the basis of information drawn from the literature and from case studies conducted in Brazil. Special reference is made to the production of charcoal and the production of alcohol and vegetal oils to replace gasoline and Diesel fuel in internal combustion engines.

The potentialities and socio-economical implications of projects based on some efficient energy crops such as sugar cane, cassava, eucalyptus and oil palm are discussed. In addition, attention is called to some plants which are considered promising sources of oil and hydrocarbons but have not yet been fully investigated from the agronomical and/or industrial point of view.

INTRODUCTION

The 70's will probably be historically recalled as the decade in which man has fully realized the importance of energy as a developmental resource. The energy problems of mankind have never deserved so much attention and discussion as in the present days. It was well known for many years that these problems would become critical in time, due to increasing world population and energy consumption per capita. As a consequence of the oil crisis which emerged in 1973, a new challenge was imposed to countries dependant on fossil fuel imports: the search for alternative sources of energy. One promising source is undoubtedly solar radiation, which is not only abundant, but also inexhaustible.

Solar radiation can be captured either as caloric energy or as electro-magnetic energy (Fig. 1). The processes for collecting solar energy as heat have thus far received more attention, thermal devices of various types being commonly employed for drying, building conditioning and refrigeration. It is important to mention that both the atmosphere and the sea water can be regarded as "natural" thermal collectors. The former, when heated by solar energy is subjected to pressure differentials and air currents are formed which ultimately can be harnessed to generate electricity. The latter, on the other hand, when evaporated by solar energy, leads to rain and the continental hydrological cycle, from which hydropower results.

The present work will deal only with electromagnetic collection of solar energy, more specifically with the utilization of solar energy via photosynthesis, the oldest and most important

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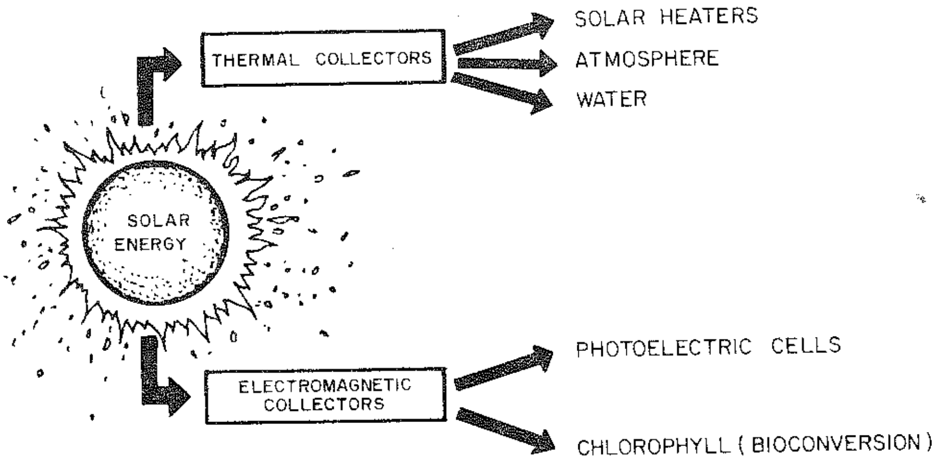

Fig. 1 Different systems of capturing solar energy.

natural way of "harvesting the sun". The "artificial" means of collecting electromagnetic energy from the sun, like the photochemical and photoelectrical processes, will not be analysed in this paper because of the remote possibility of their economical use.

POTENTIAL CROP PRODUCTIVITY IN THE TROPICS

It is well known that solar radiation is the environmental factor which sets the limit of potential biological productivity of a given region. Many undesirable environmental factors, such as plant diseases and pests, low soil fertility, moisture deficits and/or excesses, etc. often prevent the full realization of the agricultural potential of a region. These negative factors, however, can in many cases be economically controlled by man, especially when growing highly valued crops. Since no economical way of increasing solar radiation under field conditions is yet known this factor becomes theoretically the most critical one in defining the potential plant productivity in any region.

Because plant growth in the tropics is so much enhanced by the abundant solar radiation, responses to cultural practices like fertilizer application, irrigation and others, tend to be much more pronounced in tropical rather than in temperate climates. Of course, during summer days temperate zones may receive practically the same amount of solar energy, or even more than tropical ones and plants in these regions also respond proportionally to cultural practices. The favourable period of growth in temperate climates is limited, however, to a relatively short season, whilst in the tropics favourable conditions occur almost throughout the year. Thus it can be expected that increases in crop yields due to adequate cultural practices should as a rule be greater in tropical than in temperate or cold regions.

Fig. 2 illustrates the above theoretical considerations concerning the potential productivity of tropical zones. In this figure the distribution of incident solar energy as a function of latitude is plotted against estimates of potential biological productivity. Unfortunately, the information on photosynthetic efficiency in the tropics is meagre. The data presented in Fig. 2 were obtained considering a fixation of incident energy of 1% to the latitude of 50° and one of 2% to the tropical latitudes (10°-20°). The actual values found so far are generally lower

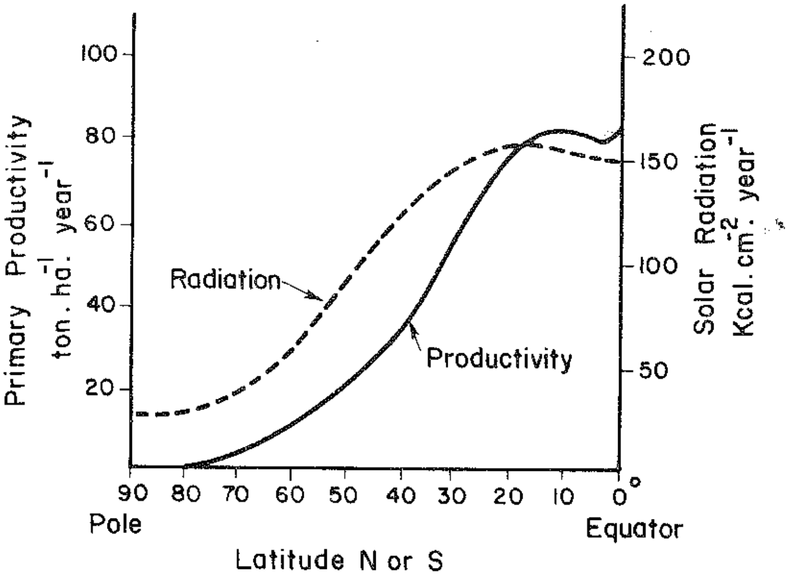

Fig. 2 Approximate values of potential primary productivity in relation to the latitude.

and average 0.5 - 1 %, but a few isolated cases are known of highly efficient crops like sugar cane, in which an annual primary productivity exceeding 90 tonnes of dry matter per hectare have been recorded (15).

These considerations lead to the conclusion that a higher crop productivity can be obtained in tropical regions than in temperate ones, provided suitable plant material and adequate cultural practices are adopted.

ENERGY CROPS

Because of the oil crisis and of the progressive decline of the fossil resources, plant cultivation with the purpose of fuel production has been considered, in recent years, as an additional role for agriculture in certain regions. As previously mentioned, this alternative is particularly interesting to tropical countries having large land availability. In such countries the available land can be exploited with a special type of agriculture dedicated to the production of substances which can be economically transformed into fuels. The "energy crops" chosen for this kind of agriculture are characterized by an ability to produce large quantities of carbohydrates (cellulose, starch, sugars) or oils. Some crops which are able to produce hydrocarbons also deserve attention, although their energetic output is lower than that of the species which yield carbohydrates and oils. The problem of fuel production from these various energy crops is analysed in the following sections.

1. Carbohydrate producing crops

The most interesting plants having a high carbohydrate storage capacity in tropical countries are sugar cane, cassava and eucalyptus. In Northeast Brazil there is also some interest in the native palm "babaçu" *(Orbygnia speciosa)* which occurs in large natural stands, specially in the State of Maranhao where this palm is found in an area exceeding 10 million hectares (4). Sugar cane and cassava are undoubtedly the most appropriate energy crops for the production of ethanol, while eucalyptus is mainly recommended for the preparation of firewood and charcoal.

Comparative data on annual field production and the yields in ethanol for the principal carbohydrate producing crops are given in Tables 1 and 2.

Table 1. Estimated annual production of various carbohydrate sources in Brazil (Menezes *et al*, 1977).

Carbohydrate source	Production (million tonnes)	Productivity (ton/ha)	
		Raw Material (*)	Carbohydrate
Sugar cane	95	45 (80)	5.7
Cassava	26	13 (25)	4.3
Sweet potato	2	15 (25)	4.1
Maize	17	1.4 (3.0)	1.1
"Babaçu"	140 (?)	10 (?)	1.7
Sweet sorghum	(?)	25 (35)	3.9

* Data on productivity represent the Brazilian national average obtained with the use of traditional cultivation methods; numbers in brackets are the average productivities which can be reached with improved cultural practices.

Table 2. Ethanol production from the main carbohydrate sources in Brazil (Menezes, *et al*, 1977)

Carbohydrate source	Raw Material (ton/ha)	Ethanol Production (*)	
		l/ton	l/ha
Sugar cane	45	67	3,015
Cassava	13	180	2,340
Sweet potato	15	125	1,875
"Babaçu"	10	86	860
Sweet sorghum	25	85	2,125

* Industrial production, which corresponds to 77% of the theoretically expected yield.

Because of their higher yields when compared with other crops, cassava and sugar cane are the plants selected to support the initial stages of the Brazilian Plan for Alcohol Production. As shown in Table 3, this plan is programing an increasing production of ethanol to be used initially in a 20% mixture with gasoline and ultimately to replace this fuel in internal combustion engines. It is expected that an annual production of 70 billion liters of ethanol will be reached by the year 2000 to meet the projected demand for that year. The plan will benefit about 1.5 million families and will operate on approximately 24 million hectares. This area corresponds to 2.8% of the country's total area (850 million ha) or 7% of the arable land (340 million ha). It is estimated that the area to be used for food and fiber production will be of approximately 100 million hectares by the year 2000 (13).

Table 3. Area required by the Brazilian Plan for Alcohol Production with estimated ethanol production and number of families which will benefit from the programe (J.G. da Silva, 1978).

Phase		Alcohol Production Target (10^6 1)	Required Area (a) (1,000 ha)	No. of families receiving benefits (b)
First	1975-1980	2,000	677	43,312
Second	1980-1990	23,000	7,784	486,544
Third	1990-2000	45,000	15,231	951,937
TOTAL		70,000	23,692	1,480,793

(a) The following figures were considered: (1) ethanol production from sugar cane: 3,546 1/ha year; (2) ethanol production from cassava: 2,532 1/ha year.

(b) Modules of 16 ha per family.

(a) and (b) It is considered that half of the ethanol is produced from cassava and half from sugar cane.

Cassava's contribution to the Brazilian Plan for Alcohol Production is still relatively small, since the first plant for this purpose has just started operating. In addition, alcohol production from sugar cane is more traditional and crop technology is much more advanced than in the case of cassava. Cassava, however, shows a few advantages when compared to sugar cane such as lower soil fertility requirement, lower cost of production and the possibility of storing the raw material.

The production of alcohol from wood can be economically feasible under certain conditions. In Brazil, however, eucalyptus has been planted with the purpose of charcoal production to be used as a reducer in the iron industry. The Brazilian Smeltery Plan is programing a considerable expansion within a period of 4-5 years with an annual target of 30 million tonnes of iron. To meet this target, an annual importation amounting 24 million tonnes of coke would be required, though this can be partly satisfied with charcoal. To comply with the demand for charcoal several areas are being cultivated with eucalyptus. In the State of Minas Gerais, for example, reforestation will cover an area which will render 3.6 million tonnes (15 million m^3) of charcoal per year. Almost 2 million ha of eucalyptus will be needed in this State to produce 10 million tonnes of iron. Several by-products are obtained during wood combustion like methanol, acetic acid and combustible gases which significantly reduce the cost of charcoal production (14).

Alcohol yields from the "babaçu" palm are very low. The starch content of its fruit mesocarp is small when compared with other carbohydrate producing crops, but this is compensated by the large areas existing in Brazil which produce about 140 million tonnes of fruits per year (Table 2). In addition, other products can be obtained from this palm such as oil from the seeds and combustible gases and charcoal from the pericarp (Table 4). The cost of harvesting and transport of the fruits is the main difficulty limiting immediate exploitation of "babaçu" as an energy crop.

Many other forest species, besides eucalyptus, will contribute to the production of energetic substances in tropical regions. It is worth mentioning, for example, the excellent results obtained with *Gmelina arborea* and *Pinus caribea* in the Brazilian Amazon. The

Table 4. Energetic utilization of "babaçu" (Carioca and Soares, 1977).

Fuel	Productivity (ton/ha)	Crude Oil Equivalent (Ton)	% Energy
Charcoal	13.5	10.8	30.1
Gas	18.9	11.3	35.9
Ethanol	13.6	8.3	27.6
Oil	4.3	0.8	5.4

"Jari Agroflorestal" has implanted, in the past 10 years, about 60,000 ha of *Gmelina* and 30,000 ha of *Pinus caribea.* The first plantings have averaged an annual wood productivity of 30 m^3 of *Gmelina* and 27 m^3 of *Pinus* per ha. These levels of productivity come near to the highest commercial wood productivity in the world and clearly demonstrate the enormous potentiality of the Amazon Region with respect to commercial wood production.

2. Oil producing plants

The African oil palm *(Elaeis guineensis)* is undoubtedly the most efficient oil producing plant in the world in terms of oil yield per unit cropped land. This crop can easily render 4-5 tonnes of oil per ha/year under ecologically favourable conditions and with the use of adequate cultural practices. Other species which are also cultivated for oil production such as soybean *(Glycine max)*, peanut *(Arachis hypogea)*, and castor bean *(Ricinus communis)* are much less productive. The coconut palm *(Cocos nucifera)* can also produce large quantities of oil but does not compare with the oil palm in average figures.

Fuel production from palm oil is much simpler than ethanol production from carbohydrates. The oil contained by fruit pressing is mainly constituted of triglycerides formed by the esterification of fatty acids with glycerine. By heating (30-40°C) the oil for a few hours in the presence of a monoalcohol and hydrochloric acid, the fatty acids can be reesterified and give up an equal amount of oil which is fusible at lower temperatures and can be used as motor fuel in Diesel engines. The monoalcohol can be either methanol or ethanol and is partially recovered in the process. The production of methyl esters following alcoholisis of the oil palm triglycerides is more interesting because, as opposed to the case where ethyl esters are prepared, the methyl esters are naturally separated and a final distillation is not necessary (8, 11, 12).

The processes for obtaining ethyl alcohol from sugar cane and cassava are compared, in Tables 5 and 6, with the extraction of palm oil, from which an equal amount of motor fuel can be prepared by alcoholisis and reesterification as described above. As shown in these tables, fuel production from oil palm is a very simple process which has the following advantages when compared to alcohol production from carbohydrates:

1. higher fuel yield;

2. saccharification, fermentation and distillation processes are not necessary;

3. smaller process heat requirement specially because distillation is not needed;

4. smaller volumes are handed. Alcohol production from sugar cane and cassava involves the manipulation of an enormous volume of fermented material, the end-product (ethanol)

Table 5. Industrial processes in the production of fuels from sugar cane, cassava and oil palm (Barreto, 1977).

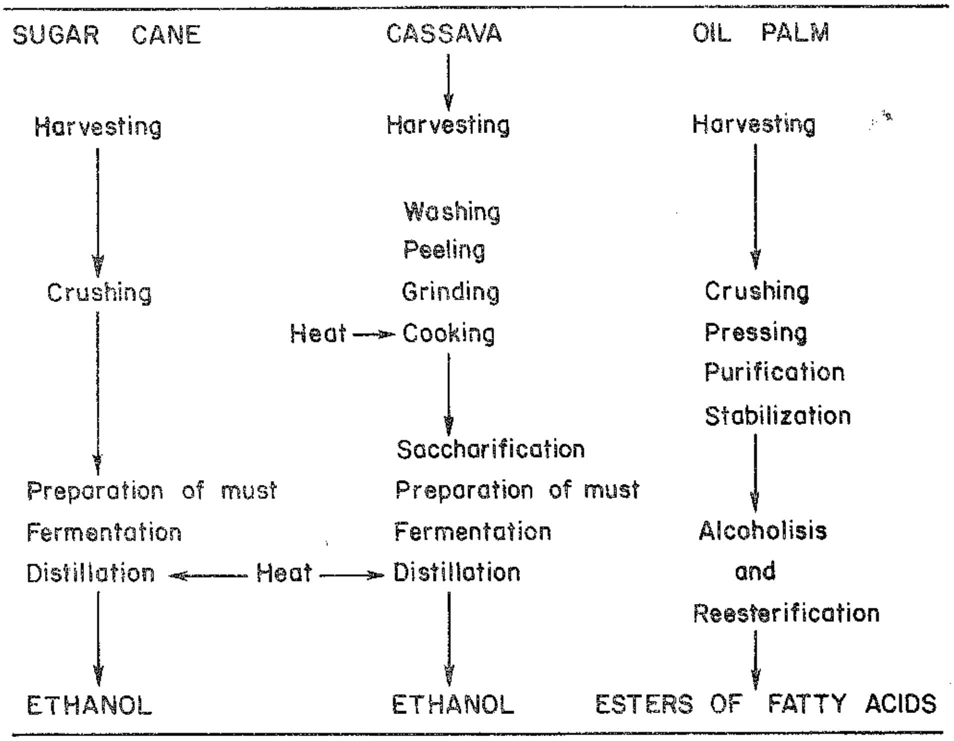

Table 6. Average fuel production from sugar cane, cassava and oil palm.

SUGAR CANE	CASSAVA	OIL PALM
50 ton/ha (stalks)	15 ton/ha (roots)	20 ton/ha (fruits)
Sugar 4 ton	Starch 4.5 ton	Oil 4 ton
Alcohol 2.8 ton	Alcohol 2.5 ton	Esters of fatty acids 4 ton

corresponding only to 10% of such material (1). Each kilogram of fuel as obtained from palm oil, on the other hand, results from the reaction of 1 kg of vegetal oil with 1.85 g of alcohol and 20 g of acid (12);

5. no pollutant residues are formed as in the case of alcoholic fermentation. On the contrary crop residues from oil extraction can be used for feeds or to be readily applied to the soil as fertilizer. Their use as fertilizer would consist in a further advantage in that mineral nutrients would be perfectly recycled since the oily material removed from the field is composed solely of carbon, hydrogen and oxygen which originate in the water and in the air. Nutrient recycling in the cases of sugar cane and cassava can not be readily performed due to the acidic nature of the industrial residues and to the large volume of water to be transferred back to the field;

6. as opposed to the cropping patterns of sugar cane and cassava, oil palm fruits are produced throughout the year and this allows for more efficient use of the industrial plant.

Provisional data show that the Brazilian demand for gasoline and Diesel oil could be satisfied with the annual production of approximately 20 million tonnes of palm oil. The area needed would be, theoretically 4 to 5 million hectares, which is equivalent to nearly 0.5% of the country's total area.

Because Brazil is the world's greatest castor-oil producing country, the castor-oil plant *(Ricinus communis)* has also been considered as an alternative energy source. In fact, some buses in the capital city Brasilia are presently using as fuel, on an experimental basis, a mixture of ethanol and castor-oil.

3. Hydrocarbon producing plants

Some plants are able to store solar energy in the form of very reduced carbon compounds: the hydrocarbons. This is the case, for example, of the rubber-tree *(Hevea brasilliensis)* whose latex consists of an aqueous emulsion containing approximately 30% hydrocarbons, mainly polyterpenes made of 1,000 - 5,000 isoprene units forming a long chain. Through special chemical treatments it is possible to crack these chains to obtain hydrocarbons similar to those found in gasoline. This process, however, would not be recommended in the case of *Hevea* hydrocarbons due to their high industrial value as elastomers. There are, however, many other plants, especially in the family of the Euphorbiaceae, that also produce hydrocarbons which can be transformed into fuel and which do not have such a high economic value as the latex obtained from the rubber-tree. One such species is presently being studied in Brazil with a view to fuel production. It grows in arid zones of Northeastern Brazil where it is commonly known as "aveloz" *(Euphorbia tirucalli)* and is used for fencing. The plant produces a latex formed of low molecular weight terpenes and terpenoids which can be converted by "cracking" into a gasoline-like fuel as well as into ethylene for industrial purposes (3).

The essential oils produced by some plants also contain a considerable quantity of hydrocarbons (terpenes and terpenoids) which can equally be transformed into motor fuel. One promising species that is being studies in Brazil for this purpose is *Croton sonderianus*, the "marmeleiro preto", a wide-spread invader of the Northeastern region. Unfortunately, no information is available concerning its agronomical potentiality, but it is estimated that this plant can produce about 200 tonnes fresh weight of biomass per hectare. Preliminary observations have shown that the oil content corresponds to 1% of the biomass on a fresh weight basis. Consequently, two tonnes of essential oils could be obtained per hectare. The oils are obtained from the whole plant tissues through steam extraction followed by condensation and water separation (5).

As a curiosity it is worth mentioning a native tree of the Amazon Region locally called "kerosene tree" or "louro mamori" *(Ocotea barcellensis)*, from which the Indians extract an oil having a strong terebinthine scent that can be used as a fuel for domestic purpose instead of kerosene (6). The oil is extracted from the main trunk. Another oil producing tree found not only in the Amazon region, but also in the forest regions of Central Brazil and in Venezuela, is the well known "copaiba" *(Copaifera langsdorfii)* from which is extracted the medicinal oil known as South American balsam or "baume de Saint Paul", used in affections of the mucous membrane as well as in varnishes. The oil is tapped by making a hole in the trunk of the tree. Unfortunately no reliable information is available regarding the potential productivity or cultural characteristics of these curious oil producing trees.

Table 7 summarizes general information on the energetic potentialities of the main plants mentioned in this paper.

Table 7. Annual fuel production from various sources in relation to their average productivity in Brazil.

FUEL	SOURCE	PRODUCTIVITY		
		ton/ha	1/ha	1/ton
ALCOHOL	SUGAR CANE *(Saccharum officinarum)*	45	3,015	67
ALCOHOL	CASSAVA *(Manihot esculenta)*	12	2,160	180
ALCOHOL	"BABAÇU" *(Orbygnia speciosa)*	3	240	80
ALCOHOL	SWEET POTATO *(Ipomoea batatus)*	15	1,875	125
ALCOHOL	SWEET SORGHUM *(Sorghum saccaratus)*	25	2,125	85
HYDROCARBONS	"AVELOZ" *(Euphorbia tirucalli)*	?	640/3,200+	?
TERPENES	"MARMELEIRO" *(Croton sonderianus)*	?	400/2,000+	10
OILS (Triglycerides)	OIL PALM *(Elaeis guineensis)*	20	4,000	200
TERPENOIDS	KEROSENE TREE *(Ocotea barcellensis)*	?	?	?

+ Estimated yields, not supported by experimental work.

THE CHALLENGES OF ENERGY FARMING

Energy farming will be particularly interesting for countries which are largely dependant on fossil fuel importation and possess an extensive area of arable land. These countries will have the opportunity to decide whether or not to keep importing fossil fuels. Even if the production of fuel from vegetal matter is marginally more expensive than the importation of fossil fuels, it may remain an attractive proposition when the advantage of additional rural employment is considered. The choice between fossil fuel importation and internal fuel generation from plant sources will be depending then on the internal economic policy of the country

With the decrease in fossil energy reserves, however, the future economic picture becomes more and more complex and new problems may be imposed. In view of the need to feed an increasing population, it is believed that land occupation in the future will have to be programmed more carefully, taking into consideration the critical equilibrium between food production and energy farming.

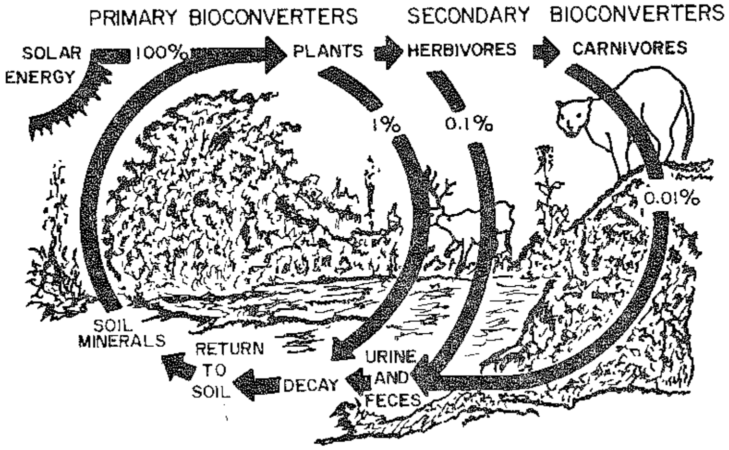

Fig. 3 Relative efficiency of the primary (plants) and secondary bioconverters (herbivores and carnivores) of a natural ecosystem in capturing solar energy (Adapted from "Man in the Living Environment". The Institute of Ecology, 1972).

With regard to the food-and-people relationship it is important to consider future trends in the use of animal and vegetal foods. Because of the increasing population pressure it is believed that a wider competition will occur between tillable and grazing land. Plants are the fundamental link in the trophic chain of a balanced ecosystem, and their ability to store solar energy is at least 10 times greater than that of the herbivores and 100 times that of the carnivores (Fig. 3). In other words, even the herbivores, which are considered the most efficient animals in terms of land occupation, need at least 10 times more land in order to store the same amount of energy as plants would do. Thus, animals may be viewed, under certain circumstances, as competitors to man, and this is illustrated in Fig. 4 which compares the protein consumption of man and of the livestock in the world. This figure is computed on the basis of an average man (70 kg), who requires a daily protein intake of 70 grams, the data being expressed in terms of "man-equivalents". It can be observed in this figure that the cattle biomass is twice that of man. By adding up all the living mass of livestock it can be concluded that there are more than 18 billion "people" in today's world, or 5-fold the real "human" population (2).

Of course, animal proteins are much more complete for man's nutrition than the ones found in plants. The great majority of cultivated plants have an inadequate content of sulfur containing amino acids which are essential to a man's balanced diet. Plant breeders have tried to develop varieties having a high content of these amino acids and some maize and sorghum varieties are actually relatively rich in lysine. It is known, however, that animal products will constitute, for many years to come, inevitable supplements to man's diet. But there are more adequate ways of producing and consuming animal proteins than the prevailing one.

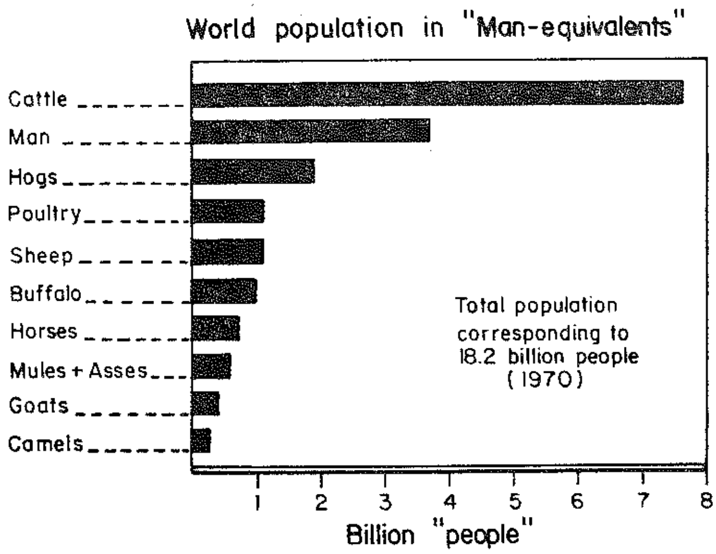

Fig. 4 Estimated world "population" based on protein consumption of animal competitors to man and expressed in terms of "man-equivalents" (Adapted from 2).

With respect to the consumption of animal food, it is worth mentioning the cases of the United States of America, Canada, France and Germany where the annual output of cereals per capita is about 1,000 kg and 900 kg are destined to animal feed. On the other hand in China, where some 200 kg of cereals are annually produced per capita, only 40 kg are used in livestock feed and the remaining 160 kg are directly employed in man's diet (9).

In fact, a substantial part of mankind hazardously eats an excessively high proportion of animal food, with serious economic and possibly also health consequences, as can be inferred by the higher incidence of heart diseases and cancer in countries where excessive meat is consumed.

With regard to increasing the production of animal protein, the previous reasoning leads to the conclusion that, in the future, it would be inefficient to use potentially tillable land to raise animals, especially with the precarious methods employed in many countries, notably in the tropics. Animal food production should be restricted to marginal land with no practical value for arable purposes.

Special forage plants are being selected and ameliorated for poorer and drier soils than those suitable to food crops. It is also believed that the methods selected for future production of animal protein will have to rely on better management practices providing adequate recycling of animal and vegetal wastes. Because fish can be fed with crop and animal residues, fish culture is particularly promising activity with respect to nutrient recycling.

Another means of improving the production of animal protein is the utilization of vegetal protein concentrates extracted from crop wastes as a feed for non-ruminants. Since ruminants can utilize plant ingredients such as cellulose and others that man's gastric system cannot digest, they considerably broaden the basis for human existence through their low-key competition (2). The non-ruminants, on the other hand, exert a high degree of competition to man but could be used as biological converters of low quality to high-quality protein if fed with crop wastes.

The next problem refers to the selection of the areas to be used in the process of capturing solar radiation with energy crops. It seems logical that the chosen land will be that of marginal qualification for the production of foods, where the soils present some problems for plant growth. This is the case, for example, of the oxisols and ultisols which are abundant in the tropics and can be successfully exploited with crops having low requirements like cassava, eucalyptus and many other woody plants of great energetic potential.

Large scale fuel production from biomass is undoubtedly a new challenge to mankind which will inevitably cause socioeconomical changes. One of its possible consequences may be the redistribution of rural and urban population. Because of the large contingent of manpower presently engaged in industrial activities around the majority of the big cities in the world, a great deal of energy is consumed in these cities, mainly with mass transportation. It is expected, however, that the present rate of rural exodus will be limited or restrained due to the additional land occupation for energy farming. It is possible, therefore, that the equilibrium between rural and urban populations is restored in the near future thus, alleviating the energy demand of the large cities.

Finally, the production of fuels from biomass is an enormous hope with respect to the future of tropical countries. The abundant fossil fuel resources existing in the past provided the necessary stimulus for the rapid agricultural development in the temperate regions of the world. In spite of the difficulties met by man in temperate zones, where climatic conditions are unfavourable for himself and for the plants during great part of the year, agriculture in these regions is more developed than in the tropics. Taking into consideration the fossil fuel depletion in the world and the enormous potential biological productivity of tropical regions, it is believed that a more balanced wealth distribution will occur in the future as a consequence of fuel production from biomass and that an economical equilibrium between temperate and tropical regions will hopefully be reached.

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